REMARKS

In the January 14, 2005 Office Action, Examiner rejected claims 1-8 under § 112, § 101, and § 103. Applicants have amended the application and believe that Examiner's objections have been fully addressed, and submit that all claims are in condition for allowance.

Rejections under § 112

The Examiner rejected claims 1 - 8 under § 112, first paragraph, as failing to comply with the written description and enablement requirements, and under § 112, second paragraph as indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as his invention.

Rejection Under 35 U.S.C. § 112, First Paragraph- Written Description

With regard to the written description rejection, the Examiner argued that the absence of particular formulas and/or equations or other means to facilitate the computations discussed in the body of the application failed to provide any pertinent teachings for dealing with the problems presented by the art. Citing specific examples of steps and sub-steps (e.g., S-3, S3-3, etc.), Examiner contended that Applicant's failure to insert correlative formula and/or equations constituted deficiencies meriting rejection of the claims.

The basic formulas, however, are generally known to those of skill in the art and are, moreover, ancillary to the substance of the invention. Applicant does not claim the equations or formulas in the abstract as the present invention. Rather, the calculations using such formulas are made in order to achieve the end objectives of the present invention, i.e., the selection of the optimal device(s) for utilization in an air blow system. Applicant's discussion at page 2, lines 6-11 of the specification, quoted by the Examiner, was not directed to the difficulty in determining

formulas to use, but rather to the application of such formulas to the problem of optimizing the design of the system.

Applicant respectfully submits that one of skill in the art would have little trouble determining applicable formulas from the known literature, such as ISO 6358:1989, entitled "Pneumatic fluid power - Components using compressible fluids - Determination of flow-rate characteristics," a copy of which is provided herewith. This standard contains, at page 12, for example, formulas for choked flow and subsonic flow that can be used at S3-5 and S-10 in Fig. 2; S6-4 in Fig. 3; S17-2, S17-7, S17-15, and S17-17 in Fig. 4; S23-6 in Fig. 5; and S26-4 in Fig. 6. Similarly, formulas for composite conductance applicable to S17-14 in Fig. 4; S23-2 in Fig. 5; and S26-1 in Fig. 6 can be found at pages 187-189 in Eckersten, J., "Simplified flow calculations for pneumatic components," Stockholm, 1975, a copy of which is provided herewith.

In addition, useful equations for S3-3, S3-4, S3-8, and S3-9 in Fig. 2; S6-2 and S6-3 in Fig. 3; and S17-11 in Fig. 4 may be readily determined by those of skill in the art who could empirically measure the relationship between pressure P_W, nozzle inner diameter D, pressure PO immediately upstream from the nozzle, and work distance L.

In view of the foregoing, Applicants respectfully request withdrawal of the written description rejection.

Rejection Under 35 U.S.C. § 112, First Paragraph - Enablement

With regard to the enablement rejection, in accordance with the Examiner's suggestion at paragraph 9 of the Office Action, Applicant has made modifications to the specification to clarify the actor in each step. Applicant has amended the specification to state clearly, e.g., "the operator inputs the data," "the system executes a calculation," etc. While Applicant maintains that one skilled in the art would recognize, for example, that any

computation would be executed by a computer system based on operator-entered values and internal programming, Applicant has nonetheless amended the specification in a manner so as to eliminate any doubt as to who the relevant actor is in each case. To further distinguish the steps and functionality performed by the invention from those performed by a human operator, Applicant has endeavored to use the active voice as reflected in the changes in the specification. Applicant therefore respectfully requests withdrawal of the enablement rejection.

Rejection Under 35 U.S.C. § 112, Second Paragraph - Indefiniteness

Applicant has also prepared revised claims to ensure that the requirements of § 112, second paragraph, have been met. For example, where a claim previously claimed the step of "inputting a nozzle diameter, a work distance, ..." the claim now clearly claims "a step in which an operator inputs current values of a nozzle diameter, a work distance, ..." Similar and uniform modifications have been made throughout the claims without affecting their scope. The Examiner's other grounds in paragraphs 11-17 of the Office Action are also believed to have been addressed in the new claims. In view of these changes, Applicant respectfully submits that the Examiner's § 112 indefinite rejection is no longer apposite.

Rejection under § 101

The Examiner asserts that the claims embrace nonstatutory matter under § 101. Office Action, p. 8. To make this argument, Examiner puts forth a claim interpretation whereby "the steps of inputting are performed by a human operator while the steps of selecting are the direct results of computation." As such, Examiner contends, the invention consists "solely of mathematical operations." Applicant respectfully disagrees with the Examiner's position, and directs the Examiner to the case of *Diamond v. Diehr*, 450 US 175 (1981). There, the Supreme

Court held that the invention - a process for molding rubber - was not merely a mathematical algorithm, despite the fact that the only truly "novel" feature of this invention was the timing process controlled by the computer. The Court went on to hold the process patentable. Since *Diehr*, the Federal Circuit has stated repeatedly that an invention must be looked at as a whole - not piecemeal - in determining whether the invention amounts to nothing more than an algorithm. Here, the invention utilizes a number of equations, and, based on user input, determines the optimal devices for use in an air flow system. The output of any equations that are utilized are not ends in themselves - rather, they operate on real world values to produce results which are further utilized to produce a concrete end result: the optimal selection of an air flow device.

Taken to its logical conclusion, the Examiner's view would render virtually all extant system or method patents that utilize or depend on computational methods nonstatutory. MPEP 2106(IV)(B)(1) cites as an example of nonstatutory processes the execution of a "mathematical algorithm" or the simple manipulation of abstract ideas. The present invention is neither. While computations are integral to the successful operation of the present invention, as the figures clearly show the present invention consists of a novel and non-obvious structuring of steps and processes resulting in an optimized system.

With regard to claims 6-8 directed to "a recording medium storing a program," Applicant has remedied any perceived issue by modifying the claims and clarifying the relationship shared between the computer, the program, and the invention generally. The amended claims set forth a computer readable medium which stores a program for selecting the optimal air blow device. Applicants respectfully submit that the rejections under 35 U.S.C. § 101 have been traversed and should be withdrawn.

Rejections under § 103

The Examiner has rejected the claims under 35 U.S.C. § 103(a) as unpatentable over the reference described as "Mechanical Engineers' Handbook," second edition edited by Myer Kutz (hereinafter "Kutz"). Kutz, argues the Examiner, teaches computations for viscous fluid flow in ducts including nozzle diameter and Bernoulli equation. Examiner alleges that although Kutz does not expressly teach a system using a computer, the Kutz reference in conjunction with that generally known in the art renders the present invention unpatentable. The Examiner concludes that the claimed invention automates the manual process of solving the equations taught by Kutz. Applicant respectfully disagrees.

The weight of Examiner's argument depends on the allegation that the present invention is merely the computerized automation of generally known equations and nothing more. First, this is a flawed premise, as the present invention more than a series of equations. Whether Kutz teaches computations for viscous fluid flow is irrelevant. The equations, despite being well-known in the art, are distinct from the steps which operate on them. In other words, a program which takes some specified input, generates an output, and executes, for example, Bernoulli's equation at some point in the calculation process, is no more obvious than a program which does not use Bernoulli's equation. Applicant respectfully submits that Examiner's rejection on the basis of the existence of basic equations in an engineers' handbook is akin to rejecting all claims that include steps executed by a computer on the basis of finding examples of multiplication in a math textbook. Neither rejection is founded on the principles of §103, which demands rejection of claims when said claims "would have been obvious at the time the invention was made to a person having ordinary skill in the art." The steps of the present

invention are intelligently and non-obviously sequenced in a manner that facilitates the achievement of the invention's objectives. The Examiner's arguments overlook the structure and arrangement of these steps and impermissibly focuses on the fact that equations are used. In the circumstances, Applicant respectfully submits that the obviousness rejection in view of the equations themselves is improper, and requests withdrawal of the rejection.

CONCLUSION

Based on the foregoing amendments and remarks, Applicant respectfully requests issuance of a Notice of Allowance. Applicant requests a two-month extension of time and submits herewith a check in the amount set forth in 37 C.F.R. § 1.17(a)(2). Applicant hereby authorizes the Commissioner to charge payment of any additional fees or credit any overpayment associated with this communication to Deposit Account No. 02-4377.

Dated: June 14, 2005

Respectfully submitted,

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Enclosures

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7.3

Simplified flow calculations for pneumatic components

Joakim Eckersten

7.3.1 Earlier sub-sections in section 7 have dealt with the resistance to flow in restrictions, nozzles, pipes, etc. As already mentioned, the theoretically derived relationships must generally be corrected by some empirical factor, to render them of practical use. As an example, the cross-sectional area of a restriction must be corrected by a coefficient of discharge, and a pipe must be corrected by a surface finish factor. Moreover, in the majority of relationships, it is difficult to express the flow and pressure as explicit functions of each other. As a result, a number of simple mathematic expressions have been derived, in which constants are adjusted to suit the empirically established flow characteristics of the component.

This sub-section will deal with the most important of these empirically adjusted formulae. The formula has been derived by Sanville at the University of Bath, and this formula together with an associated measuring method has been assumed as a provisional recommendation for a CETOP standard for measurements of pneumatic components (CETOP RP50P, in force since the 20th June 1973). The formula is an elliptical approximation of the relationship between pressure and flow.

7.3.2 The equation of flow

The equation for flow through a passive component with a flow area independent of the pressure and flow can be expressed as:

$$q = C \cdot p_1 \cdot K_t \cdot w \qquad \text{(air of 100 kPa (1 bar), +20°C)} \qquad (7.80)$$

where

$$w = \begin{cases} 1 & \text{for} \quad p_2/p_1 \leq b \\ \{1-[(p_2/p_1-b)/(1-b)]^2\}^{1/2} & \text{for} \quad 1 \geq p_2/p_1 \geq b \end{cases}$$

$$K_t = (293.15/T)^{1/2}$$

For pressure drop calculations, equation (7.80) can also be re-written as

$$p_1 - p_2 = (1-b)\cdot\left\{p_1 - [p_1^{\,2} - (q/C)^2]^{1/2}\right\} \qquad (7.81)$$

Equation (7.80) is adjusted empirically by the factors »C» and »b» being established in accordance with the measurement standard mentioned above. »C» specifies the conductance of the component, i.e its ability to conduct flow (figure 7.15). The factor »b» specifies a derived critical pressure ratio of the relevant component.

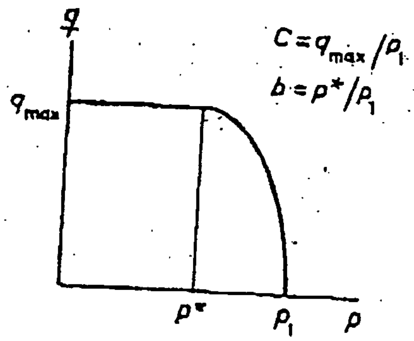

Fig. 7.15 - Characteristic flow curves for a pneumatic component

Note: For estimating purposes it is practical to use:

$$q = 0.23\cdot(1+b)\cdot C\cdot p_1 \qquad (1/s)$$

where p_1 is the absolute supply pressure (bar).

The formula gives the flow at a pressure drop of 3% of p_1. The margin of error is less than 5% provided that $b < 0.6$.

7.3.3 Factors "b" and "C" for various components

Pneumatic systems include valves, couplings, filters, etc. of various sizes and makes. The values of »b» and »C» obviously differ from size to size, but also from make to make. Some typical values are presented in table 7.2. Exact values for a specific component can be obtained from the corresponding data sheet, or by measurements in accordance with CETOP RP50P. Since the standard is still

Table 7.2

		1/8"	1/4"	1/2"	1"
tube length 1 m	*b*	0.32	0.41	0.50	0.56
	c	$0.67 \cdot 10^{-8}$	$3.14 \cdot 10^{-8}$	$16.5 \cdot 10^{-8}$	$76 \cdot 10^{-8}$
bend 90 degree	*b*	0.40	0.30		
	c	$1.6 \cdot 10^{-8}$	$4.7 \cdot 10^{-8}$		
directional control valve	*b*	0.25	0.2	0.2	0.2
	c	$0.8 \cdot 10^{-8}$	$4 \cdot 10^{-8}$	$16 \cdot 10^{-8}$	$50 \cdot 10^{-8}$
filter	*b*	0.2	0.05		
	c	$3.5 \cdot 10^{-8}$	$8 \cdot 10^{-8}$		

Note: the *c*-values above are expressed in $m^3/s/Pa$. In order to get them in 1/s/bar, they should be multiplied by 10^8

new, it may take some time before the values of »b« and »C« are generally available for the majority of components.

Two components which differ from one system to the next are the pipe and the restriction. Tubes have different lengths, depending on their locations in the system, and restrictions are specific to the design of the system. A method has been developed for calculating the values of »b« and »C« for these components. The same relationship (see below) is applicable to the tube and the restriction, i.e. the tube can be regarded as a long restriction.

The values of »b« and »C« are calculated for the tube and the restriction in accordance with the theoretically established relationship, which is empirically adjusted.

$$C = 0.029 \cdot d^2/(L/d^{5/4} + 510)^{1/2} \tag{7.82}$$

and the corresponding value of »b«

$$b = 474 \cdot C/d^2 \tag{7.83}$$

The above value of »C« is applicable to tubes without couplings.

In the above formulae, the values of »C« are for the pascal as the

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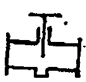
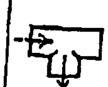
unit of pressure and m^3/s as the unit for volume rate of flow. If the bar is used as the unit of pressure, and l/s as the unit for volume rate of flow, the values must be multiplied by the factor 10^8.

Since the material is as yet incomplete as regards the values of »b» and »C» for various components, a frequently employed table specifying the equivalent tube lengths for various components is available (table 7.3).

Table 7.3

Pipe fittings			tube inner diameter (mm)						
			25	40	50	80	100	125	150
Seat valve		L	3-8	5-10	7-15	10-25	15-30	20-50	25-60
		C	65-50	165--140	250--210	680--560	1000--900	1600--1300	2300--2000
Diaphragm valve		L	1.2	2.0	3.0	4.5	6	8	10
		C	70	190	290	750	1100	1800	2600
Diaphragm valve, straight flow path or gate valve		L	0.3	0.5	0.7	1.0	1.5	2.0	2.5
		C	80	200	310	800	1250	2000	2800
Elbow		L	1.5	2.5	3.5	5	7	10	15
		C	70	180	280	740	1100	1800	2500
Elbow $R = d$		L	0.3	0.5	0.6	1.0	1.5	2.0	2.5
		C	75	200	310	800	1250	1955	2815
Elbow $R = 2d$		L	0.15	0.25	0.3	0.5	0.8	1.0	1.5
		C	80	200	320	820	1300	2000	2800
Hose coupling T-piece		L	2	3	4	7	10	15	20
		C	65	175	275	710	1100	1700	2400
Reducer $2d \rightarrow d$		L	0.5	0.7	1.0	2.0	2.5	3.5	4.0
		C	75	200	300	790	1200	1900	2750

Note: L = equivalent tube length, (m)

The C-values above are expressed in l/s/bar. In order to get them in $m^3/s/Pa$, they should be multiplied by 10^{-8}

7.3.4 Components connected in series

There are two methods of calculating the flow characteristics (C_s, b_s) of a pneumatic system when the flow characteristics of each component (C_i, b_i) are given for the components connected in series. The first method, known as the "additivity" method, is easy to use and provides the flow characteristics of a system, with an error below 10%. The second method, known as the method of consecutive additions, considers the order of components and provides the flow characteristics of a system more accurately, with an error below 5%. This latter method is well suited for calculation with programmable calculators.

Considering a system of n components connected in series as shown in figure 7.16, the flow characteristics are calculated as follows.

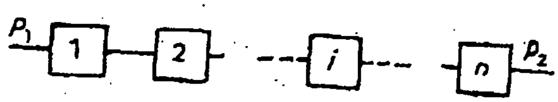


Fig. 7.16 - Components connected in series

7.3.4.1 The "additivity" method

The conductance of the system (C_s) is first calculated

$$1/C_s^3 = \sum_{i=1}^{n} (1/C_i^3) \qquad (7.84)$$

The critical pressure ratio (b_s) is then calculated

$$(1-b_s)/C_s^2 = \sum_{i=1}^{n} [(1-b_i)/C_i^2] \qquad (7.85)$$

With these two values C_s and b_s, it is now possible to calculate the flow characteristics of the system by using equation (7.80) or (7.81).

7.3.4.2 The method of consecutive additions

The calculation is performed in n-1 steps (figure 7.16). The two first components 1 and 2 are considered in the first step.

For these two components, the value of α is calculated

$$\alpha = C_1/(C_2 \cdot b_1) \tag{7.86}$$

if $\alpha < 1$

then, when the pressure drop across both components is increased, the flow first becomes choked in component 1. Choked flow in component 2 occurs after further increase in pressure drop.

if $\alpha > 1$

then the flow only becomes choked in component 2

if $\alpha = 1$

then the flow becomes choked in both components at the same time.

The two components 1 and 2 are added to represent a new compounded component 1,2.

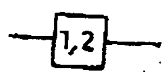


Fig. 7.17

The values $b_{1,2}$ and $C_{1,2}$ for the compounded component are calculated as follows

for $\alpha \leq 1$

$$C_{1,2} = C_1 \tag{7.87}$$

for $\alpha \geq 1$

$$C_{1,2} = C_2 \cdot \alpha \cdot \left[\alpha \cdot b_1 + (1 - b_1) \cdot \left\{\alpha^2 + [(1 - b_1)/b_1]^2 - 1\right\}^{1/2}\right] / \left\{\alpha^2 + [(1 - b_1)/b_1]^2\right\} \tag{7.88}$$

for all α

$$b_{1,2} = 1 - C_{1,2}^2 \cdot [(1 - b_1)/C_1^2 + (1 - b_2)/C_2^2] \tag{7.89}$$

The second step, in the procedure is to add the third component to the first two.

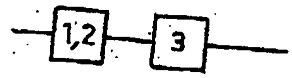


Fig. 7.18

A new value for α is calculated from equation 7.86 as

$$\alpha = \frac{C_{1,2}}{C_3 \cdot b_{1,2}}$$

and new values for $b_{1,2,3}$ and $C_{1,2,3}$ are calculated in accordance with above equations (7.87) - (7.89). The procedure is continued until all components in the system have been treated and the $b_{1,2,3\ldots n}$ and $C_{1,2,3\ldots n}$ will be the characteristic values for the system. The flow characteristics for the system can now be calculated from equations (7.80) or (7.81).

.3.5 Components connected in parallel

The method described below is based upon the same basic treatment of theory as that underlying the above "additivity" method.

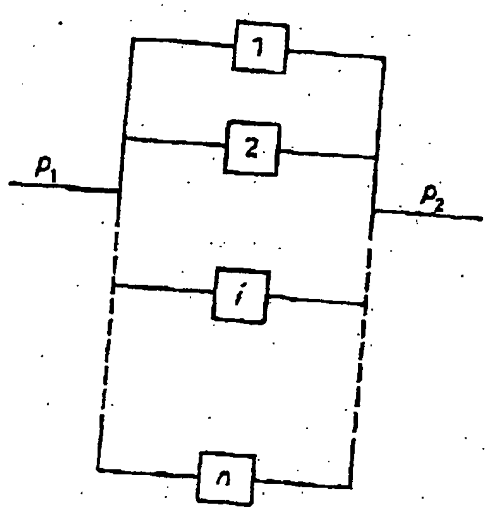


Fig. 7.19 - Components connected in parallel

The conductance of the system (C_s) is calculated as

$$C_s = \sum_{i=1}^{n} C_i$$

(7.90

And the corresponding value for the critical pressure ratio of the system (b_s) is calculated as

$$C_s/(1-b_s)^{1/2} = \sum_{i=1}^{n} C_i/(1-b_i)^{1/2}$$

(7.91)

As mentioned earlier for the other methods, the flow characteristic of the system can now be calculated from equations (7.80) or (7.|

Examples

For the cylinder application shown in figure 7.20 it is required establish the values b and C from point A to B.

From equations (7.82) and (7.83) the »b» and »C»-values for the tube can be calculated

$b_1 = 0.29$

$C_1 = 2.17 \cdot 10^{-8}$ (m³/s/Pa)

$b_3 = 0.23$

$C_3 = 1.76 \cdot 10^{-8}$ (m³/s/Pa)

For the valve, the »b» and »C»-values are, known from a leaflet or measured

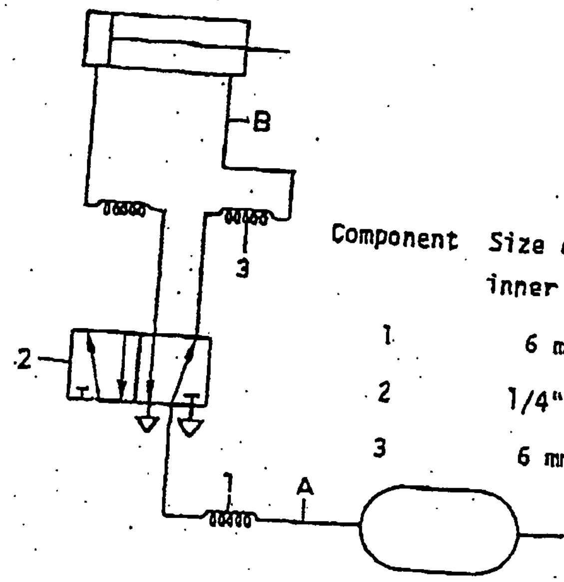
$b_2 = 0.23$

$C_2 = 3.9 \cdot 10^{-8}$ (m³/s/Pa)

From equations (7.84) and (7.85), the approximate »b» and »C»-values are obtained as follows

$$1/C_s^2 = 1/(2.17 \cdot 10^{-8})^2 + 1/(3.9 \cdot 10^{-8})^2 + 1/(1.76 \cdot 10^{-8})^2 \Rightarrow \underline{C_s = 1.35 \cdot 10^{-8}} \quad (m^3/s/Pa)$$

$$(1-b_s)/(1.35 \cdot 10^{-8})^2 = (1-0.29)/(2.17 \cdot 10^{-8})^2 + (1-0.23)/(3.9 \cdot 10^{-8})^2 + (1-0.23)/(1.76 \cdot 10^{-8})^2 \Rightarrow \underline{b_s = 0.1}$$



Component	Size or tube inner dia.	Length
1	6 mm	3 m
2	1/4"	valve
3	6 mm	5 m

Fig. 7.20 - Calculation of a typical pneumatic system

The more accurate method of equations (7.86) - (7.89) gives

$\alpha = (2.17 \cdot 10^{-8})/(3.9 \cdot 10^{-8} \cdot 0.29) = 1.92$

α is greater than one, therefore use equation (7.88). This gives

$C_{1,2} = 2.05 \cdot 10^{-8}$ $(m^3/s/Pa)$

and equation (7.89) gives

$b_{1,2} = 1 - 2.05 \cdot 10^{-8} [(1 - 0.29)/(2.17 \cdot 10^{-8})^2 + (1 - 0.23)/(3.9 \cdot 10^{-8})^2] = 0.155$

$\alpha' = (2.05 \cdot 10^{-8})/(1.76 \cdot 10^{-8} \cdot 0.155) = 7.5$

α' is greater than one. Equation (7.88) gives

$C_{1,2,3} = \underline{C_s = 1.375 \cdot 10^{-8} \approx 1.4 \cdot 10^{-8}}$ $(m^3/s/Pa)$

$b_{1,2,3} = \underline{b_s = 0.15}$

In the circuit shown in figure 7.21, the pressure p_2 is to be found at a flow rate of q_v = 90 l/s = 0.09 m^3/s, when the supply pressure p_1 = 0.7 MPa

The »b« and »C«-values are for components number 1, 3, 5 and 6 fetched from tables 7.2 and 7.3. The »b« and »C«-values for the tubes are calculated from equations (7.82) and (7.83).

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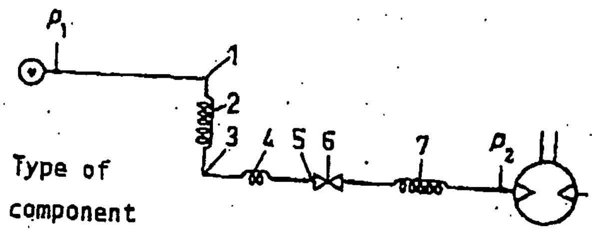

Component	Size of tube inner dia.	Type of component
1	50 mm	elbow
2	50 mm	tube 20 m
3	50 mm	elbow
4	50 mm	tube 1 m
5	50/25 mm	area red.
6	1"	valve
7	25 mm	tube 15 m

Fig. 7.21 - Flow calculation of a typical pneumatic system

$b_1 = 0.25$ $C_1 = 280 \cdot 10^{-8}$ $(m^3/s/Pa)$

$b_2 = 0.23$ $C_2 = 196 \cdot 10^{-8}$ $(m^3/s/Pa)$

$b_3 = 0.25$ $C_3 = 280 \cdot 10^{-8}$ $(m^3/s/Pa)$

$b_4 = 0.58$ $C_4 = 308 \cdot 10^{-8}$ $(m^3/s/Pa)$

$b_5 = 0.5$ $C_5 = 200 \cdot 10^{-8}$ $(m^3/s/Pa)$

$b_6 = 0.2$ $C_6 = 60 \cdot 10^{-8}$ $(m^3/s/Pa)$

$b_7 = 0.31$ $C_7 = 40 \cdot 10^{-8}$ $(m^3/s/Pa)$

The method of consecutive additions gives

$b_s = 0.20$

$C_s = 31.5 \cdot 10^{-8}$ $(m^3/s/Pa)$

and from equation 7.81 we derive the pressure drop between p_1 and p_2 in figure 7.21

$$\Delta p = (1 - 0.20) \cdot \left\{7 \cdot 10^5 - \left[(7 \cdot 10^5)^2 - (0.09/(31.5 \cdot 10^{-8}))^2\right]^{1/2}\right\} \approx 48770 \approx 0.05 \text{ MPa}$$

$$p_2 = 0.7 - 0.05 = 0.65 \text{ MPa}$$

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INTERNATIONAL STANDARD

ISO 6358

First edition
1989-10-01

Pneumatic fluid power — Components using compressible fluids — Determination of flow-rate characteristics

Transmissions pneumatiques — Éléments traversés par un fluide compressible — Détermination des caractéristiques de débit

Reference number
ISO 6358 : 1989 (E)

Contents

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 6358 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*.

Annex A forms an integral part of this International Standard. Annexes B, C, D and E are for information only.

Introduction

In pneumatic fluid power systems, power is transmitted and controlled through a gas under pressure within a circuit.

Components composing such a circuit are inherently resistive and affect the flow through it. It is therefore necessary to carry out tests to ascertain the characteristics of these components in order to determine their suitability.

Many components composing a pneumatic circuit operate under conditions of choked flow. This International Standard specifies tests at choked flow in recognition of these conditions.

Pneumatic fluid power — Components using compressible fluids — Determination of flow-rate characteristics

1 Scope

This International Standard specifies a method for testing pneumatic fluid power components which use compressible fluids, i.e. gases, to enable their flow-rate characteristics under steady-state conditions to be compared.

It specifies requirements for the test installation, the test procedure and the presentation of results.

Accuracy of measurement is divided into two classes (A and B) which are explained in annex A.

General background information is given in annex B and the basic theoretical equations are given in annex C. Guidance as to the use of practical units for the presentation of results is given in annex D.

This International Standard generally applies to those fluid power components up to and including 20 mm nominal bore used with compressible fluids (gases), the internal flow passages of which remain constant during testing. Examples of such components are

a) directional control valves, flow control valves, quick exhaust valves, etc.;

b) moving part logic devices.

It may also apply to components larger than 20 mm nominal bore but this may require the provision of exceptionally large flow generating equipment.

Two test methods are described according to the type of component. There are also two sets of characteristic constants: C and b; and A and s, respectively (as defined in 3.2 to 3.6). These may be calculated from the results.

The first set of characteristics (C and b) applies to cases where comparison of similar components is required, or when calculations of pressure and flow involve a single component only.

The second set of characteristics (A and s) is necessary when the flow behaviour of several components which are connected in series is to be estimated. This set may also be used as an optional alternative to the first set for simple flow calculations and for comparison of components.

This International Standard does not apply to components which exchange energy with the fluid (gas), for example cylinders, accumulators, etc.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 228-1 : 1982, *Pipe threads where pressure-tight joints are not made on the threads — Part 1: Designation, dimensions and tolerances.*

ISO 261 : 1973, *ISO general purpose metric screw threads — General plan.*

ISO 1179 : 1981, *Pipe connections, threaded to ISO 228-1, for plain end steel and other metal tubes in industrial applications.*

ISO 5598 : 1985, *Fluid power systems and components — Vocabulary.*

3 Definitions

For the purposes of this International Standard, the definitions given in ISO 5598 and the following definitions apply. It should be borne in mind, however, that the following definitions may differ from those given in other specific International Standards.

3.1 choked flow: Occurrence when upstream pressure, p_1, is high in relation to the downstream pressure, p_2, such that the velocity in some part of the component becomes sonic. The mass flow of the gas is proportional to the upstream pressure, p_1, and independent of the downstream pressure, p_2.

3.2 critical pressure ratio, b: Pressure ratio (p_2/p_1) below which flow becomes choked.

3.3 sonic conductance, C: Mass flow rate through the component, q_m^*, divided by the product of the upstream

pressure, p_1, and the mass density at standard conditions ϱ_0 (see table 2) when the flow is choked, i.e.

$$C = \frac{q_m^*}{\varrho_0 p_1} \text{ at } T = T_0$$

NOTE — The numerical value of C depends upon the values chosen for the standard reference atmosphere.

3.4 coefficient of compressibility effect, s: Coefficient which takes into account the effects of the gas compressibility when flow is subsonic (see D.2.3).

3.5 effective area, A: Mass flow rate throughout the component, q_m, divided by the square root of twice the product of the pressure drop, Δp, and the mass density of the gas ϱ_2, i.e.

$$A = \frac{q_m}{\sqrt{2 \varrho_2 \Delta p}}$$

This applies only when the pressure drop is small in relation to p_1 such that compressibility effects are insignificant, i.e. when $\Delta p / p_1 < 0{,}02$.

4 Symbols and units

4.1 The symbols and units used throughout this International Standard are as shown in table 1.

Table 1 — Symbols and units

Reference	Description	Symbol	Dimension 1)	SI units 2)
3.5	Effective area	A	L^2	m^2
3.2	Critical pressure ratio	b	pure number	
3.3	Sonic conductance	C	L^4TM^{-1}	$s \cdot m^4/kg$
—	Absolute static pressure (equal to the relative static pressure plus the atmospheric pressure)	p	$ML^{-1}T^{-2}$	Pa 3)
—	Mass flow rate	q_m	MT^{-1}	kg/s
—	Volume flow rate at standard conditions	q_V	L^3T^{-1}	m^3/s
—	Gas constant (for a perfect gas)	R	$L^2T^{-2}\Theta^{-1}$	J/(kg·K)
3.4	Coefficient of compressibility effect	s	pure number	
—	Absolute temperature	T	Θ	K
—	Pressure drop $(p_1 - p_2)$	Δp	$ML^{-1}T^{-2}$	Pa 3)
—	Mass density	ϱ	ML^{-3}	kg/m^3

1) M = mass; L = length; T = time; Θ = temperature

2) The use of practical units for the presentation of results is described in annex D.

3) 1 Pa = 1 N/m²

4.2 The numerals used as subscripts and the asterisk (*) used as a superscript to the symbols listed in table 1 are as specified in table 2.

Table 2 — Subscripts and superscripts

Superscript	Subscript	Meaning
	0	Standard reference conditions, i.e.: T_0 = 293,15 K; p_0 = 100 kPa (1 bar 1)); 65 % relative humidity
	1	Upstream conditions
	2	Downstream conditions
*		Conditions during sonic flow tests

1) 1 bar = 100 kPa = 0,1 MPa; 1 Pa = 1 N/m²

4.3 The graphical symbols used in figures 1 and 2 are in accordance with ISO 1219.

5 Test installation

5.1 Test circuit for components with inlet and outlet ports

A suitable test circuit as shown in figure 1 shall be used.

5.2 Test circuit for components which exhaust directly to atmosphere

A suitable test circuit as shown in figure 2 shall be used.

NOTE — Figures 1 and 2 illustrate basic circuits which do not incorporate all the safety devices necessary to protect against damage in the event of component failure. It is important that those responsible for carrying out the test give due consideration to safeguarding both personnel and equipment.

5.3 General requirements

5.3.1 The test components shall be installed and operated in the test circuit in accordance with the manufacturer's operating instructions.

5.3.2 A filter shall be installed which provides a standard of filtration approved by the test component manufacturer.

5.3.3 A test set-up shall be constructed from the items listed in table 3.

NOTE — Items A to H inclusive are essential and the remaining items I to L are chosen by the experimenter to suit the prevailing conditions.

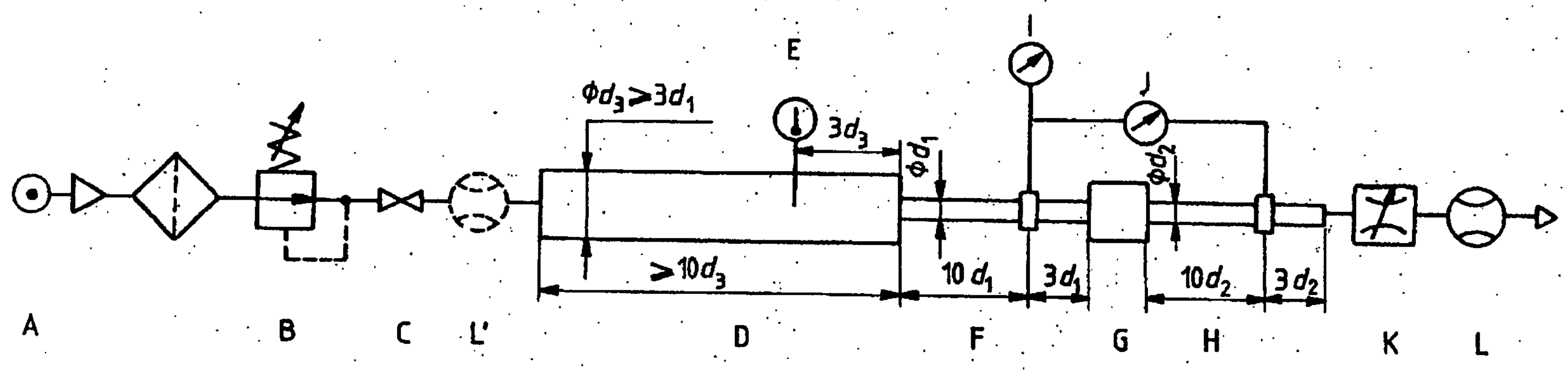

Figure 1 — Test circuit for components with inlet and outlet ports[1]

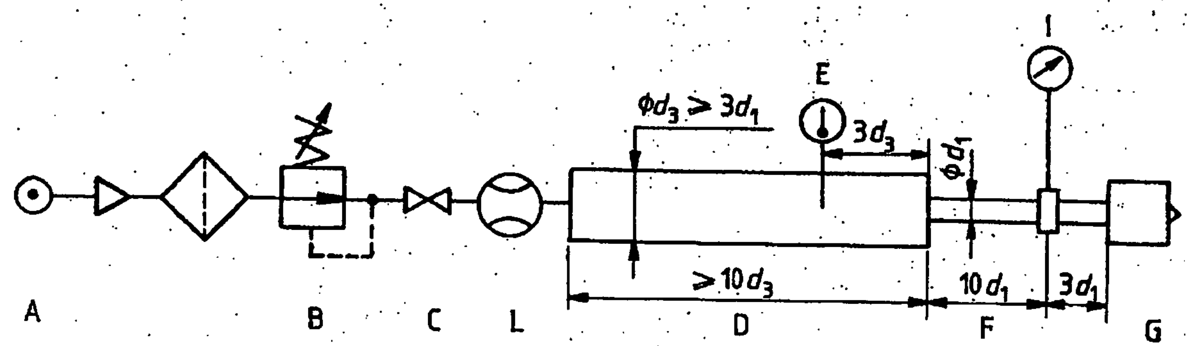

Figure 2 — Test circuit for components which exhaust directly to atmosphere[1]

1) See table 3 for key to circuit items.

Table 3 — Key to test circuit components

Reference letter	Relevant sub-clause(s)	Description	Comments
A	5.3.2 6.1.1.2	Compressed gas source and filter	
B	—	Adjustable pressure regulator	
C	—	Shut-off valve	Preferably with straight flow path
D	5.4	Temperature-measuring tube	
E	—	Temperature-measuring instrument	Sensor located on axis of D at a distance $3d_3$ upstream of end of D
F	5.5	Upstream pressure-measuring tube	
G	—	Component under test	
H	5.5	Downstream pressure-measuring tube	
I	—	Upstream pressure gauge or transducer	
J	—	Differential pressure gauge or transducer	When Δp > 100 kPa (1 bar), this gauge may be replaced by a downstream pressure gauge or transducer
K	—	Flow-control valve	To have a flow-rate capacity greater than the component under test
L	—	Flow-rate measuring device	May also be placed in position L′ upstream of D

5.3.4 All connections for pressure measurement shall be arranged in such a manner that no trap can form or retain entrained liquid; a drain may be provided.

5.4 Temperature-measuring tube (item D)

A tube shall be provided with an internal diameter, d_3, which is not less than three times the internal diameter, d_1, of the inlet pressure-measuring tube (item F) and with a length not less than ten times its internal diameter, d_3.

5.5 Pressure-measuring tubes (items F and H)

5.5.1 Tubes which conform with figure 3 shall be provided. Typical dimensions of the pressure-measuring tubes are also stated in table 4.

The tube shall be straight with a smooth, circular internal surface, and a constant diameter throughout its length.

There shall be no obstruction or branch connection other than those specified.

5.5.2 One or more pressure-tapping holes shall be provided in accordance with figure 3.

The longitudinal centreline of the tube shall intersect with the centrelines of the holes and the centrelines of the holes shall be normal to the longitudinal centreline.

The junction of each hole with the internal surface of the tube shall be sharp edged and free from burrs.

5.6 Special requirements

5.6.1 When the component under test has ports which are not threaded and other means of connecting to pipes or hoses are used, measuring tubes having internal diameters which correspond to the appropriate pipe or hose internal diameters shall be used.

5.6.2 If these diameters do not correspond, measuring tubes of the next largest internal diameter in the range shall be used.

5.6.3 When the component under test has ports which differ in size, measuring tubes which are suited to the relevant port shall be used.

6 Test procedures

6.1 Test conditions

6.1.1 Gas supply

6.1.1.1 The gas used shall be stated in the test report.

6.1.1.2 The gas shall be filtered and conditioned to comply with the recommendations of the test component manufacturer.

6.1.2 Checks

Periodically check that the pressure-tapping holes are not blocked by liquids or solid particles.

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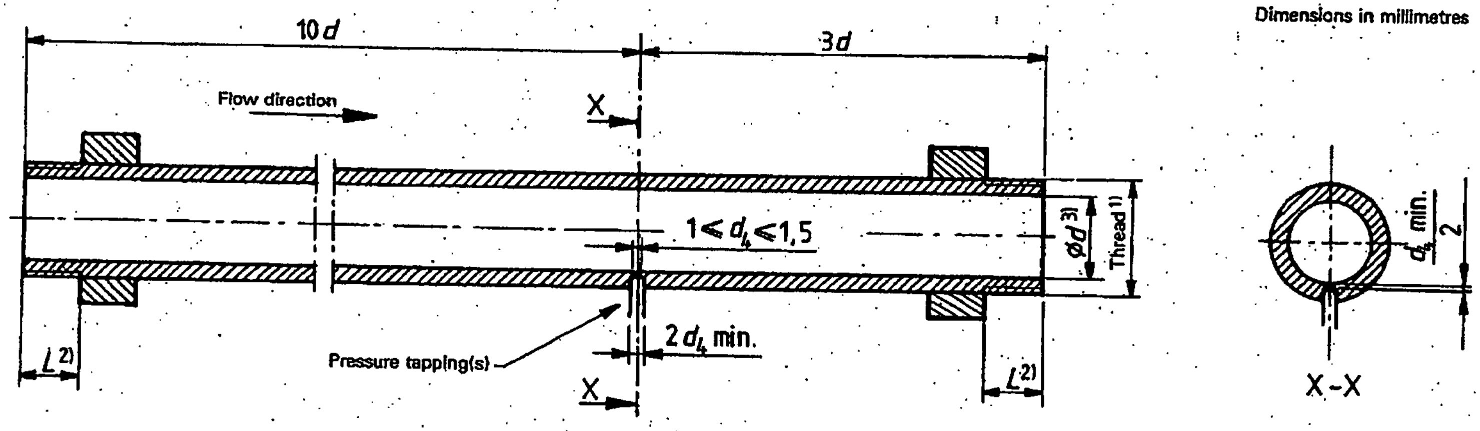
Dimensions in millimetres



1) Thread to suit component under test.

2) Thread length to suit component under test.

3) Actual internal diameter of tube.

Figure 3 — Pressure-measuring tube

Table 4 — Typical dimensions of pressure-measuring tubes

Dimensions in millimetres

Thread 1)	d	L 2) max.
M5 × 0,8	2	2,5
G 1/8	6	7,4
G 1/4	9	11
G 3/8	13	11,4
G 1/2	16	15
G 3/4	22	16,3
G 1	28	19,1
G 1 1/4	36	21,4
G 1 1/2	43	21,4

1) M threads in accordance with ISO 261; G threads in accordance with ISO 228-1.

2) G thread lengths in accordance with ISO 1179.

6.3 Calculation of characteristics

6.3.1 Sonic conductance, C

Calculate the sonic conductance from the following equation:

$$C = \frac{q_m^*}{\varrho_0 p_1^*} \sqrt{\frac{T_1^*}{T_0}}$$

where T_1^* is the value of T measured while the flow is choked.

6.3.2 Critical pressure ratio, b

6.3.2.1 If the upstream temperature remained constant during the test, calculate the value of b, for each value of q_m, from the following simplified equation:

$$b = 1 - \frac{\dfrac{\Delta p}{p_1}}{1 - \sqrt{1 - \left(\dfrac{q_m}{q_m^*}\right)^2}}$$

6.3.2.2 If variations in p_1 and T occurred during the test, calculate the value of b, for each value of q_m, from the following equation:

$$b = 1 - \frac{\dfrac{\Delta p}{p_1}}{1 - \sqrt{1 - \left(\dfrac{q_m}{C\,\varrho_0\,p_1}\sqrt{\dfrac{T_1}{T_0}}\right)^2}}$$

6.3.2.3 Calculate the critical pressure ratio as the mean value of b, for each value of q_m, calculated in accordance with either 6.3.2.1 or 6.3.2.2.

6.3.2.4 Calculate the ratio p_2^*/p_1^*. If this ratio is greater than the critical ratio b, retest with lower values of p_2 or higher values of p_1 to ensure that choked flow has been achieved.

6.3.3 Coefficient of compressibility effect, s

Calculate the coefficient of compressibility effect from the following equation:

$$s = \frac{1}{1 - b}$$

6.3.4 Effective area, A

Calculate the effective area from the following equation:

$$A = C\,\varrho_0 \sqrt{s\,R\,T_0}$$

NOTE — If, when testing a component in accordance with 6.2.2, it is found that choked flow is not reached, the effective area A may be calculated from the equation defined in 3.5.

7 Presentation of test results

7.1 All measurements and the results of calculations shall be tabulated by the testing agency and, where specified or when appropriate, shall also be presented graphically as described in 6.2.2.4.

7.2 The following performance characteristics related to flow-rate capacity and flow, which are calculated in accordance with 6.3, shall be stated; from these characteristics the performance of the component can be predicted and compared, either in the form a) and b), or the form a) or b):

a) sonic conductance, C, and critical pressure ratio, b;

NOTE — Parameters C and b will be valid only for the gas used in the test.

b) effective area, A, and coefficient of compressibility effect, s.

NOTE — Parameter s will also be valid only for the gas used in the test.

7.3 The class of measurement accuracy, i.e. A or B from annex A, shall be stated and the calibration record shall be available.

8 Identification statement (Reference to this International Standard)

Use the following statement in test reports, catalogues and sales literature when electing to comply with this International Standard:

"Test for the determination of flow-rate characteristics conforms to ISO 6358, *Pneumatic fluid power — Components using compressible fluids — Determination of flow-rate characteristics.*"

6.1.3 Test measurements

6.1.3.1 Each set of test readings shall be recorded after steady-state conditions have been reached.

6.1.3.2 The variations in upstream parameters shall be within the tolerances stated in table 5.

Table 5 — Permissible variations in indicated values of upstream parameters

Class of measurement accuracy (see annex A)	A	B
Variation in temperature indication, K	± 1	± 2
Variation in pressure indication, %	± 1	± 2
Variation in flow rate indication, %	± 2	± 4

6.1.3.3 Maintain flow conditions constant in each flow path within the component while taking measurements to ensure there is no inadvertent movement of component parts.

6.2 Measuring procedure

According to the design of the component under test, either of the procedures described in 6.2.1 or 6.2.2 shall be followed.

6.2.1 Component with upstream and downstream measuring tubes

6.2.1.1 Maintain a constant upstream pressure, p_1, of not less than 400 kPa (4 bar) and preferably higher.

6.2.1.2 Decrease the downstream pressure, p_2, using the flow control valve K, until a further decrease no longer produces an increase in the mass flow rate, q_m; this is the indication of choked flow.

6.2.1.3 Measure temperature, T^*, upstream pressure, p_1^*, mass flow rate, q_m^*, and downstream pressure, p_2^*.

6.2.1.4 Partly close the flow control valve K to reduce the mass flow rate, q_m, to approximately 80 % of q_m^*.

6.2.1.5 Adjust the pressure regulator B as required to maintain p_1 at a constant value throughout the test.

6.2.1.6 Measure the flow rate, q_m, temperature, T, and pressure differential, Δp.

6.2.1.7 Repeat the steps described in 6.2.1.4, 6.2.1.5 and 6.2.1.6 with q_m equal to 60 %, 40 % and 20 % of q_m^*.

6.2.2 Component exhausting directly to atmosphere

6.2.2.1 Measure atmospheric pressure, p_2, and temperature, T_0, and set the upstream pressure, p_1, to approximately 10 kPa (0,1 bar) higher than p_2.

6.2.2.2 Measure the mass flow rate, q_m, temperature, T, and upstream pressure, p_1.

6.2.2.3 Set the upstream pressure successively at approximately 150 kPa (1,5 bar), 300 kPa (3 bar), 500 kPa (5 bar), etc., and repeat the step described in 6.2.2.2.

6.2.2.4 Compute values for $q_m \sqrt{T/T_0}$ and plot them against p_1, as shown in figure 4.

NOTE — Choked flow is indicated when the plotted points are found to lie on a straight line directed from the origin.

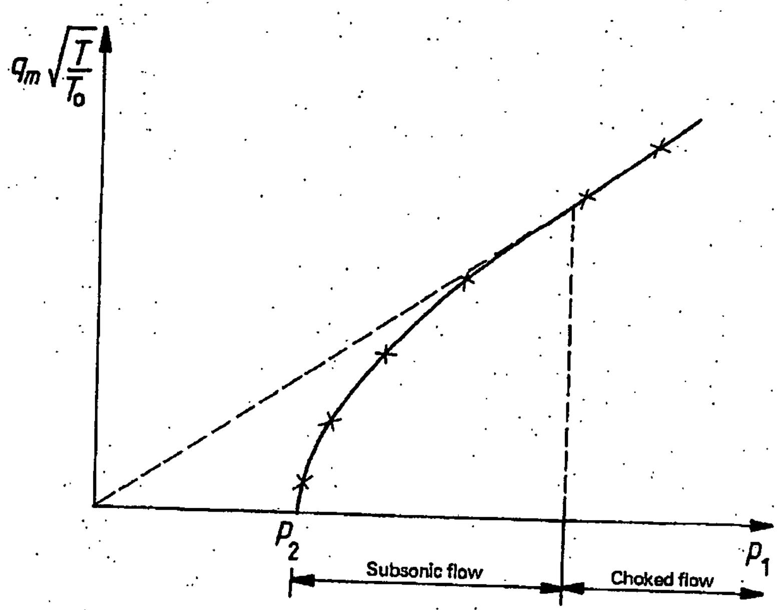


Figure 4 — Plot of mass flow rate against upstream pressure

Annex A
(normative)

Errors and classes of measurement accuracy

NOTE — The contents of this annex are under review and may be subject to amendment in the future.

A.1 Classes of measurement accuracy

Depending on the accuracy required, the tests shall be carried out to one of two classes of measurement, A or B.

The class of measurement accuracy shall be stated.

NOTES

1 Class A is intended for special cases when there is a need to have the performances more precisely defined.

2 Attention is drawn to the fact that class A tests require more accurate apparatus and methods, which increase the costs of such tests.

A.2 Errors

Any device or method shall be used which, by calibration or comparison with International Standards, has been proven to be capable of measuring with systematic errors not exceeding the limits given in table A.1.

NOTE — The percentage limits given in table A.1 apply to the value of the quantity being measured and not to the maximum values of the test or the maximum reading of the instrument.

Table A.1 — Permissible systematic errors of measuring instruments as determined during calibration

Parameter of measuring instrument	Permissible systematic errors for classes of measurement accuracy	
	A	B
Flow rate, %	± 2	± 4
Pressure, %	± 1	± 2
Temperature, K	± 1	± 2

A.3 Combination of errors

When an end result is calculated from several measurements, the combination of errors involved in that result may be determined by the root mean square method.

EXAMPLE

In this simplified method

$$C = \frac{q_m^*}{\varrho_0 p_1^*} \sqrt{\frac{T_1^*}{T_0}}$$

$$\frac{\delta C}{C} = \sqrt{\left(\frac{\delta q_m}{q_m}\right)^2 + \left(\frac{\delta p}{p}\right)^2 + 0{,}25\left(\frac{\delta T_1}{T_1}\right)^2}$$

The systematic errors used above, δq_m, δp and δT_1, are the actual systematic errors of the instruments and not the maximum values given in table A.1. For more precise summation of errors refer to *Vocabulary of legal metrology — Fundamental terms* published by the International Organization of Legal Metrology.

A.4 Expected variations

The method given in A.3 may give variations of up to ± 15 % on results due to deviations in repeatability and in laboratory conditions.

Annex B
(informative)

General information

B.1 When, for constant absolute upstream pressure and temperature, the mass flow rate of compressible fluid through a component is measured as a function of the ratio of the downstream and upstream pressures, and the data points are plotted, a typical graph as in figure B.1 is obtained.

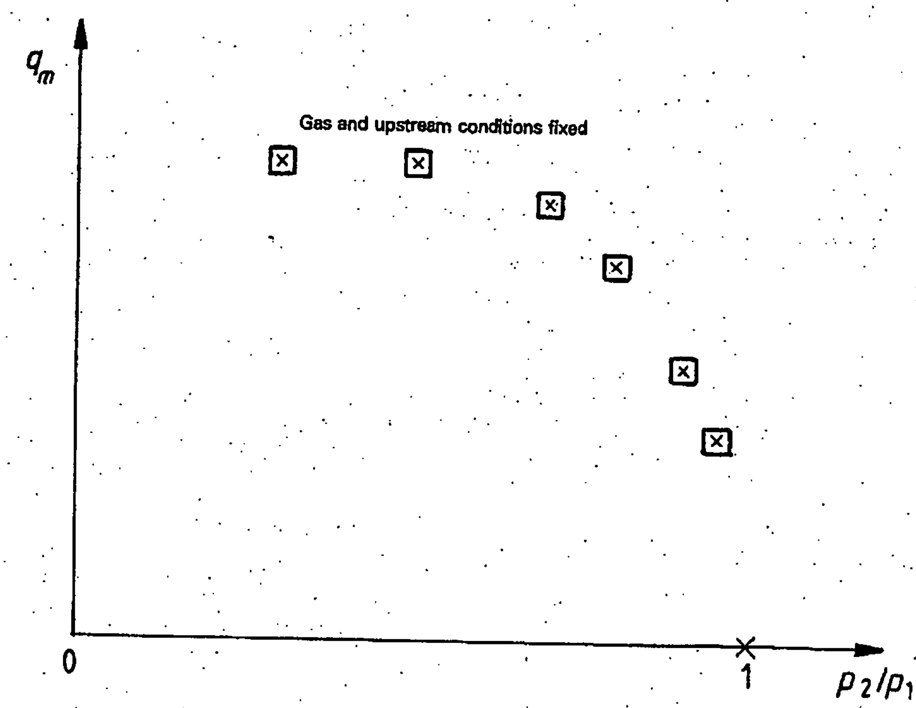


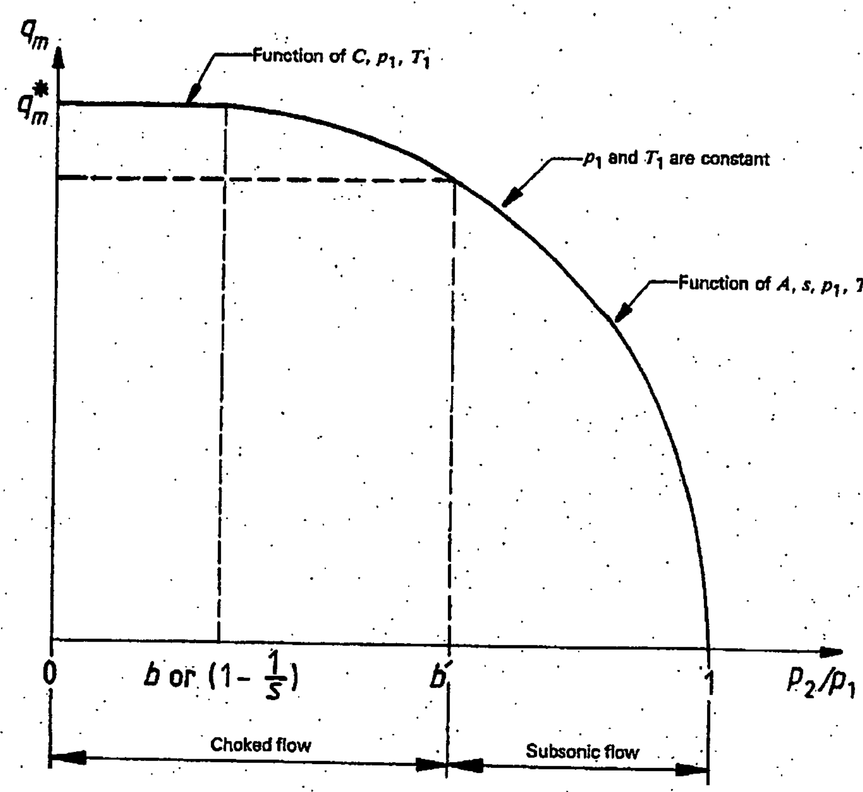
Figure B.1 — Typical representation of mass flow rate against pressure ratio 1)

1) The rectangles represent the measurement uncertainty.

B.2 The results are more useful if an analytical curve is fitted through the points and if the coefficients are related to the upstream conditions and the nature of the gas. The accuracy of the representation becomes better when the number of independent coefficients used increases, but the difficulty of use also increases.

B.3 Using a simplified model of the components and the general laws of thermodynamics, it is possible to derive adequate theoretical equations for such a curve using only two independent coefficients. After calculating the coefficients from experimental data, the curves may be fitted to the points plotted from the graph.

It has been shown that when the velocity at some part of a pneumatic component becomes sonic, the flow remains nearly constant with constant upstream pressure and when the velocity is smaller, the curve $q_m = f(p_2/p_1)$ is nearly elliptical. The general representation used in this International Standard is given in figure B.2.



NOTE — Choking usually occurs at the outlet; in cases where the choking throat lies within the component and there is also a significant pressure drop between the throat and the point of measuring p_2, the curve is distorted as indicated by the thick dashed line.

Figure B.2 — General presentation of mass flow rate against pressure ratio

B.4 Moreover, it has been found experimentally that for most of the components used in pneumatic fluid power practice, or when the accuracy of the measurements is not very high, the model can be further simplified. It is then assumed that the relationship between mass flow rate and pressure ratio can be approximately described by a quarter of an ellipse, which smoothly joins the horizontal part of the curve, as shown in figure B.3. This representation corresponds to the method of measurement adopted in this International Standard.

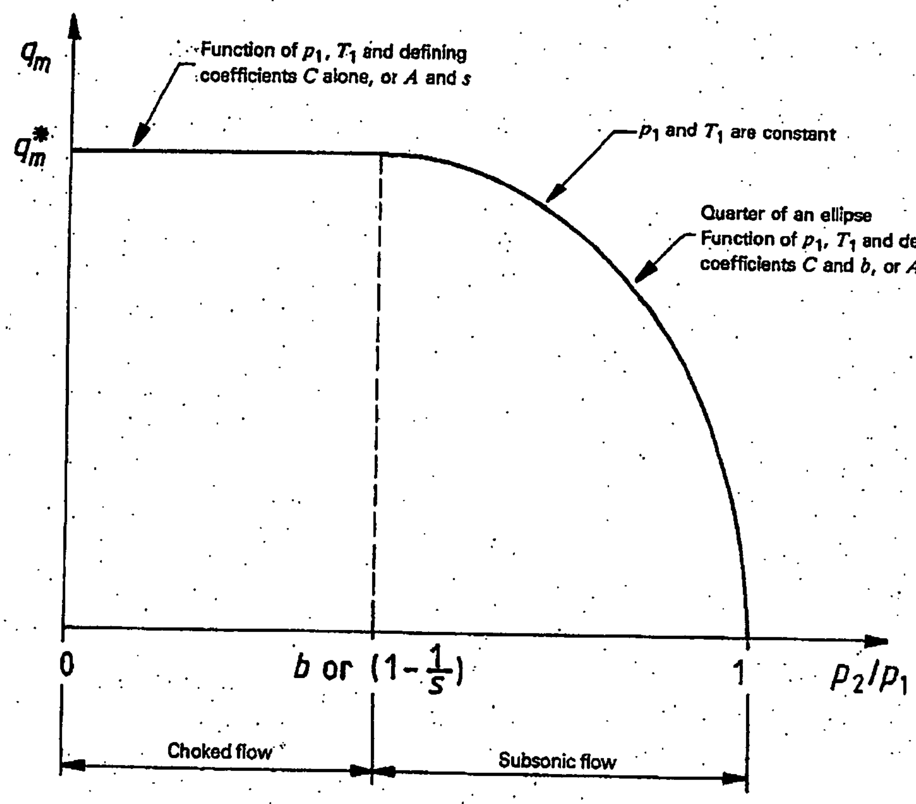


Figure B.3 — Method of presentation used in this International Standard

Annex C
(informative)

Basic theoretical equations

The flow performance of a compressible fluid component is completely described, by either of two equivalent groups of equations, each using two independent constant parameters.

Group 1 equations

— For choked flow, i.e. when $p_2/p_1 < b$,

$$q_m^* = C p_1 \varrho_0 \sqrt{\frac{T_0}{T_1}}$$

— For subsonic flow, i.e. when $p_2/p_1 > b$,

$$q_m = C p_1 \varrho_0 \sqrt{\frac{T_0}{T_1}} \sqrt{1 - \left(\frac{\frac{p_2}{p_1} - b}{1 - b}\right)^2}$$

This last equation may also be written as follows:

$$\frac{p_1 - p_2}{p_1} = (1 - b)\left\{1 - \sqrt{1 - \left[\left(\frac{T_1}{T_0}\right)\left(\frac{q_m}{C p_1 \varrho_0}\right)^2\right]}\right\}$$

Group 2 equations

— For choked flow, i.e. when $\Delta p/p_1 > 1/s$,

$$q_m^* = A \times \frac{p_1}{\sqrt{R T_1}} \times \frac{1}{\sqrt{s}}$$

— For subsonic flow, i.e. when $\Delta p/p_1 < 1/s$,

$$q_m = A \times \frac{p_1}{\sqrt{R T_1}} \sqrt{2 \frac{\Delta p}{p_1}\left(1 - s \frac{\Delta p}{2 p_1}\right)}$$

This last equation may also be written as follows:

$$\frac{\Delta p}{p_1} = \frac{1}{s}\left\{1 - \sqrt{1 - \left[s R T_1 \left(\frac{q_m}{A p_1}\right)^2\right]}\right\}$$

Annex D
(informative)

Use of practical units

D.1 Practical units

The results of the test may be presented in either tabular or graphical form using the practical units as given in table D.1.

Table D.1 — Practical units

Quantity	Symbol	Practical unit
Effective area	A	mm^2
Critical pressure ratio	b	—
Sonic conductance	C	$dm^3/(s \cdot kPa)$ or $dm^3/(s \cdot bar)$ *)
Absolute static pressure	p	kPa (bar)
Mass flow rate	q_m	g/s
Volume flow rate at standard conditions	q_V	dm^3/s (ANR)
Gas constant	R	$J/(kg \cdot K)$
Coefficient of compressibility effect	s	—
Absolute temperature	T	K
Pressure drop $(p_1 - p_2)$	Δp	kPa (bar)
Mass density	ϱ	g/dm^3

*) 1 bar = 10^5 Pa = 10^5 N/m^2

D.2 Calculations

In order to present results in practical units as given in table D.1 and using volumetric gas flow rate, the formulae given in this International Standard shall be modified as follows:

D.2.1 Sonic conductance (see 6.3.1), in cubic decimetres per second kilopascal or decimetres per second bar

$$C = \frac{q_V^*}{p_1^*} \sqrt{\frac{T^*}{T_0}}$$

at standard conditions

D.2.2 Critical pressure ratio (see 6.3.2)

$$b = 1 - \frac{\dfrac{\Delta p}{p_1}}{1 - \sqrt{1 - \left(\dfrac{q_V}{Cp_1} \sqrt{\dfrac{T}{T_0}}\right)^2}}$$

or if upstream conditions T and p_1 remain constant during the test, the calculation may be simplified as follows:

$$b = 1 - \frac{\dfrac{\Delta p}{p_1}}{1 - \sqrt{1 - \left(\dfrac{q_V}{q_V^*}\right)^2}}$$

D.2.3 Coefficient of compressibility effect (see 6.3.3)

$$s = \frac{1}{1 - b}$$

D.2.4 Effective area (see 6.3.4), in square millimetres

$$A = 3{,}442\, C \sqrt{s}$$

for air only

D.2.5 Gas constant (for a perfect gas), in joules per kilogram kelvin

$$R = 288$$

for air only 1)

D.2.6 Mass density at standard conditions, in grams per cubic decimetre

$$\varrho_0 = 1{,}185$$

for air only 1)

D.2.7 Basic theoretical equations (see annex C)

D.2.7.1 Group 1 equations may be used as written with practical units.

D.2.7.2 To use the group 2 equations, replace A by $100\,A$ to convert them to use with practical units.

1) At standard atmosphere, i.e. T_0 = 293,15 K, 65 % relative humidity, p_0 = 100 kPa (1 bar).

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Annex E
(informative)

Bibliography

ISO 1219 : 1976, *Fluid power systems and components — Graphic symbols.*

UDC 62-85 : 621.646 : 532.57

Descriptors : pneumatic fluid power, pneumatic equipment, components, tests, determination, flow rate.

Price based on 14 pages